CCT Based White Balance Adjustment

1 Abstract

This article is intended to provide a relatively simplistic explanation of what the color temperature of light is, how it is perceived, where the information is useful, and how to apply it. Our vision, how we see light, is broken into 2 categories, photopic & scotopic. Photopic vision is dominated by the red, green & blue cone cells in the human eye. Scotopic is vision is dominated by the black and white rod cells. In bright light we see colors and our vision is mostly photopic. As the light dims, we lose the ability to discern colors and our vision become scotopic. We will focus solely on the photopic region of the eye which can detect color.

In the normal world where we live there are 2 sources of visible light, artificial & sunlight. Atmospheric effects cause sunlight to vary at high color temperatures roughly in the range of 5000 to 10000K. Incandescent lighting is around 2800K (A illuminant defined at 2856K). Fluorescent lighting can be found in between. Color temperature is a measurement of the "hue" of the light source. As can be seen in the Figure 1 top axis low color temperatures appear orange, while high color temperature appear blue. The bottom axis is labeled in MIREDs which is how light is perceived by the human eye. As seen by the average human eye a white light is near 5500K, or $180MK^{-1}$.

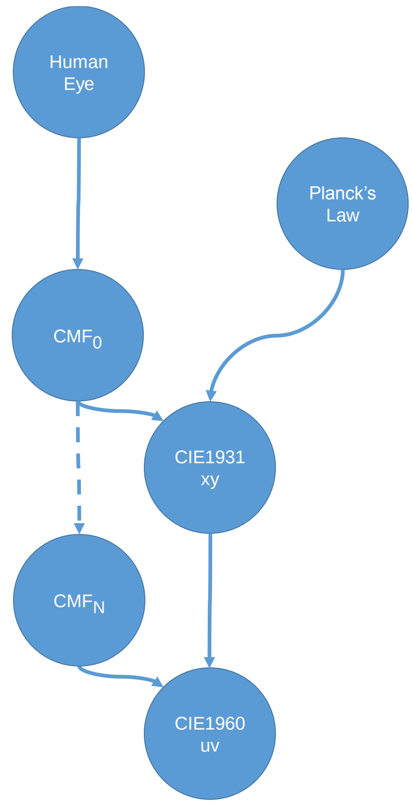
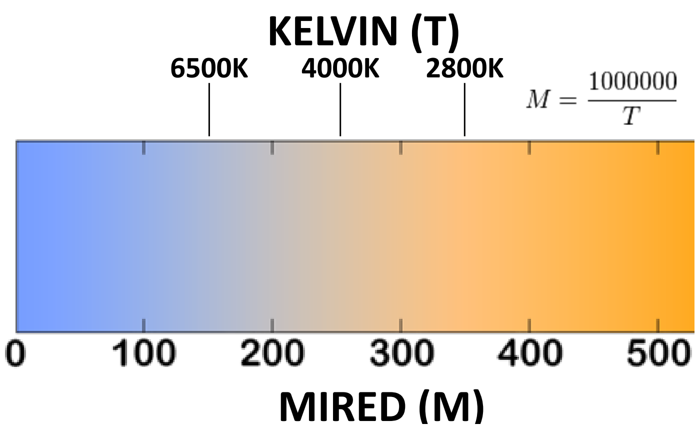


Figure 1 Hues of the Planckian locus in the mired scale. (1)



2 The Human Eye: Rods, Cones, Fovea

The human sees color with cones in reasonable lighting & switches to the rods in dark lighting where differentiation in color becomes no longer possible. The color response of the cone cells is described by the color matching functions (CMF). The CMF response curves are also effected by the field of view (FOV) which the color is perceived. The FOV is measured from the fovea, the center of acute vision. The International Commission on Illumination (CIE) has various standards for the CMF functions measured from both 2° and 10° "observers".

Figure 2 Relative Acuity of vision from the Fovea (2)

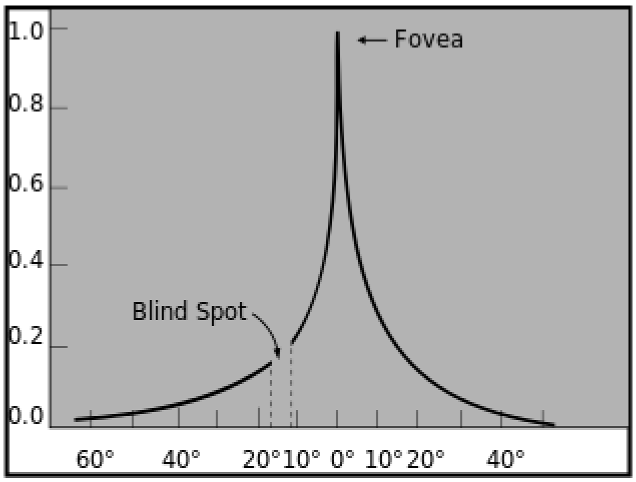
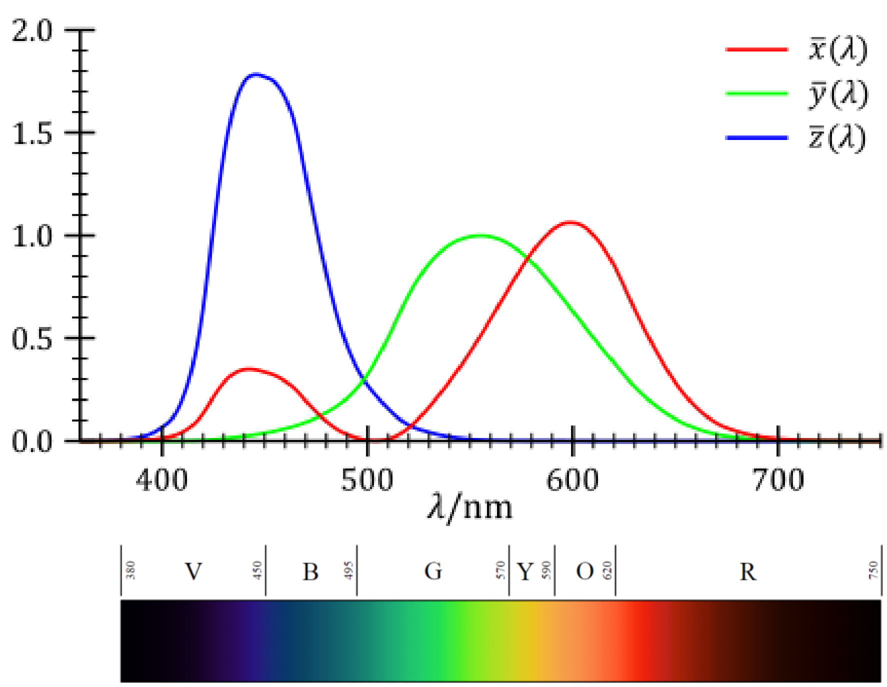


Figure 3 Original CIE 1931 Color Matching Functions (3,4)



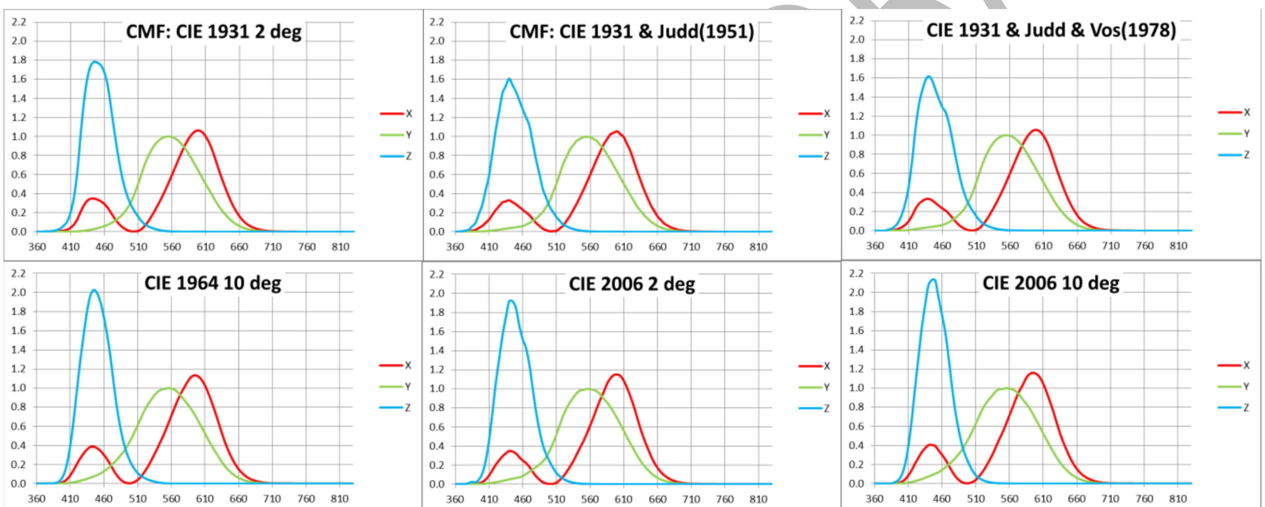
3 Color Temperature: Planckian Locus (white points) & CMF (Color Matching Functions)

The color content of light

3.1 Color Matching Functions ($\bar{x}$, $\bar{y}$, $\bar{z}$)

The color matching function show the average human eye response as a function of the wavelength of light. Several different versions of the color matching functions have been either accepted or proposed by the CIE over the years since the original in 1931 including ones which measure different fields of view of the human eye, namely 2° and 10°. A comprehensive listing of them can be found at the [Colour & Vision Research Laboratory](#).

Figure 4 CIE Color Matching Functions



3.2 Planckian Locus

The Planckian Locus is defined in Figure 5 in the XYZ color space. I(λ) shown in Figure 5 is equal to E_λ shown in Figure 6 and Figure 7.

Figure 5 Planckian Locus: XYZ Color Space (3)

$$X = \int_{380}^{780} I(\lambda)\,\overline{x}(\lambda)\,d\lambda \qquad Y = \int_{380}^{780} I(\lambda)\,\overline{y}(\lambda)\,d\lambda \qquad Z = \int_{380}^{780} I(\lambda)\,\overline{z}(\lambda)\,d\lambda$$

Figure 6 Planck's Radiation Law (5,6)

$$E_\lambda = \frac{8\pi hc}{\lambda^5} \times \frac{1}{\exp\left(hc/kT\lambda\right) - 1}.$$

h: Planck constant = 6.62606957 × 10^{-34} js

c: speed of light = 299,792,458 m/sec

k: Boltzmann constant = 1.380650 × 10^{-23} j/K

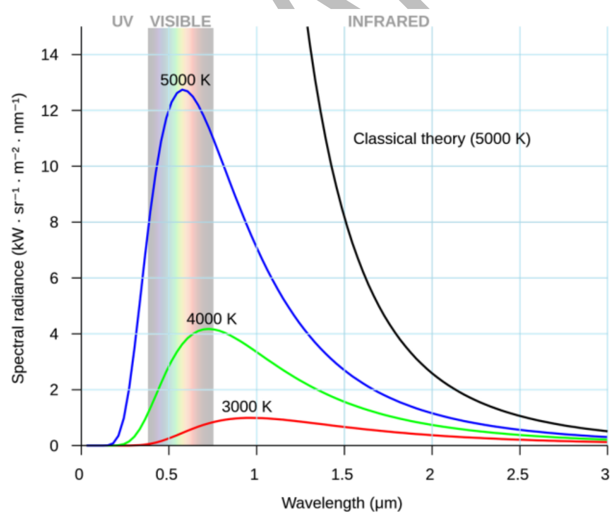


Figure 7 2.8kK to 6.5kK Black Body Curve at equal Lux Levels in 22.5MK^{-1} steps

$$\frac{E_\lambda = \dfrac{8\pi hc}{\lambda^5} \times \dfrac{1}{\exp\left(hc/kT\lambda\right) - 1}.}{Y = \displaystyle\int_{380}^{780} I(\lambda)\,\overline{y}(\lambda)\,d\lambda}$$

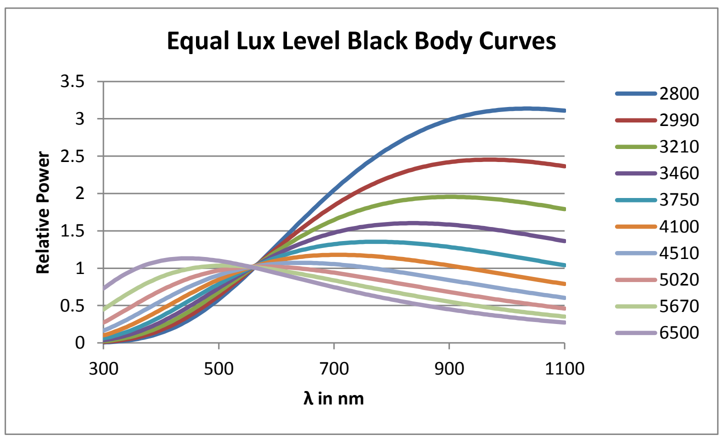


Figure 8 VBA Blackbody (Planck's Radiation) Function

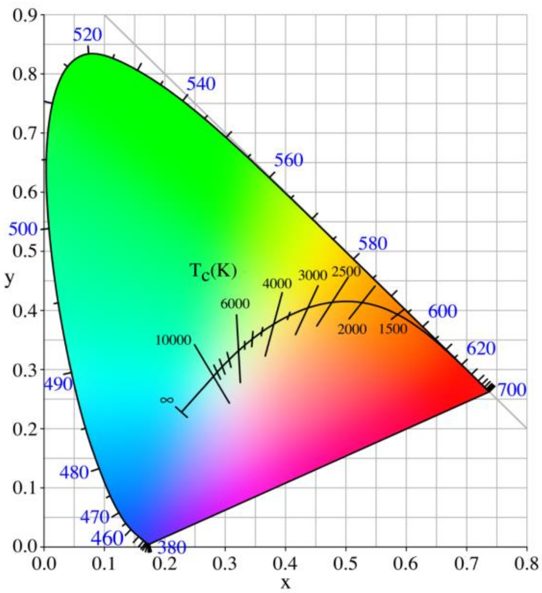
```
Public Function getBlackBody(ByVal t As Double, ByVal wl As Double) As Double
    ' t: color temperature in K
    ' wl: wavelength in nm
    'references: http://www.britannica.com/EBchecked/topic/462936/Plancks-radiation-law

    Const h As Double = 6.62606957 * 10 ^ -34 ' Planck constant (J-sec)
    Const k As Double = 1.3806488 * 10 ^ -23 ' Boltzmann constant (J/K)
    Const c As Double = 2.99792458 * 10 ^ 8 ' Speed of light (m/sec)
    Const e As Double = 2.718282 ' natural logarithm base
    Const pi As Double = 3.141592654

    wl = wl * 0.000000001 ' convert to meters

    getBlackBody = (8 * pi * h * c / (wl ^ 5)) * (1 / (e ^ (h * c / (wl * k * t)) - 1))

End Function
```

4 Color Systems

4.1 CIE: 1931/1960/1976: xy, uv, Lab

The original CIE1931 color space is shown in Figure 9. The 3 dimensional tristimulus values of X, Y & Z are represented by 2 dimensional x & y values which represent the color balance independent of the brightness (Y). This color system is shown in Figure 9. The pure color, rainbow ranging from blue to green to red lie on the upper perimeter of the figure. This is called the spectral locus. The Planckian locus is shown in labeled T_c(K).

Figure 9 CIE1931: Original xy representation of XYZ color space



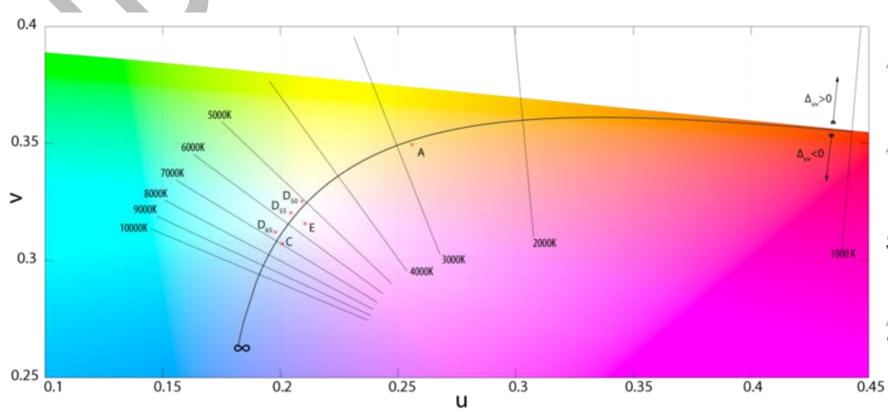
$$x = \frac{X}{X + Y + Z}$$

$$y = \frac{Y}{X + Y + Z}$$

For Y = 1:
X=x/y
Z=(1-x-y)/y

The CIE1960 color space was developed for the purpose of describing color temperature. Figure 10 shows the Planckian Locus in the uv color space. The color temperature lines shown in the figure are perpendicular to the Locus and the length represents the area where the color temperature value is considered valid (±.05 duv).

Figure 10 CIE1960: uv Color Space



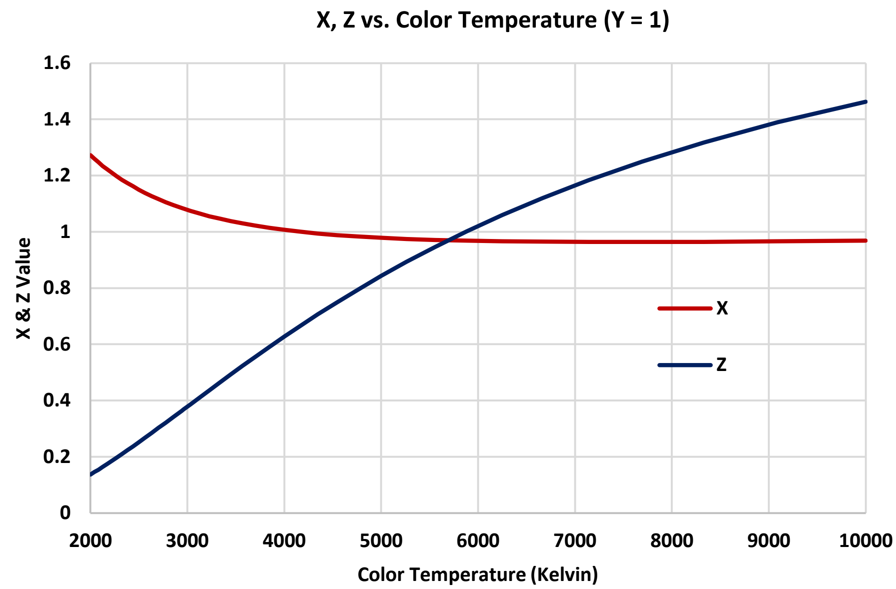
$$u = \frac{4x}{12y - 2x + 3}$$

$$v = \frac{6y}{12y - 2x + 3}$$

$$x = \frac{3u}{2u - 8v + 4}$$

$$y = \frac{2v}{2u - 8v + 4}$$

Figure 11 Relative X & Z vs. CCT



5 Photography: Color Correction

Correct to “E”

5.1 Color Perception

What color your eye sees is a combination of 3 items. The spectrum of the light, the spectral reflectivity of the object and the spectral response of your eye.

Figure 12 Color perception: 3 main contributors

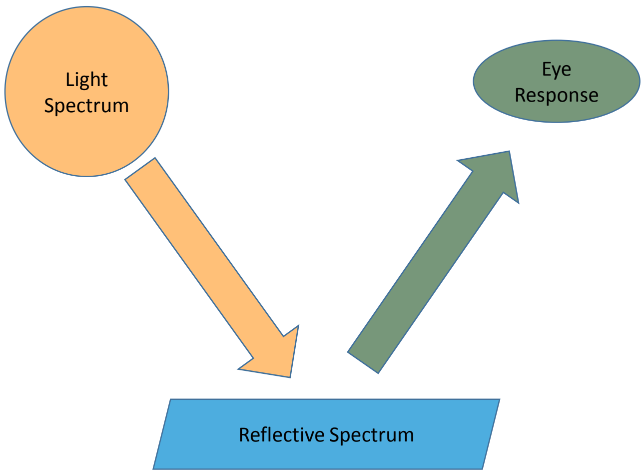


Figure 13 illustrates the effects of low color temperature light source on a blue object. The eye sees the object as a dark green vs. the blue which would be seen in sunlight.

Figure 13 shows the effect of color temperature & intensity on a series of Munsell colors. The colors in the 6329K column correspond to those in the E_V=0 column.

Figure 13 Same Munsell Colors from T: A → D65 & E_V: +⅓ → -1

Color Temperature(K); E_V=0		
2964	3983	6329

E_V; T=6329K				
+⅓	0	-⅓	-⅔	-1
100%	81%	64%	51%	41%
255	230	205	182	162
Max RGB Value				

5.2 Color Correction

The human eye sees red, green and blue content of a grey scale object at equal energy levels with light source near 5500K. At this point X=Y=Z. Where this point falls is dependent on which version of the CMFs you choose to use.

Figure 14 Relative X & Z vs. CCT

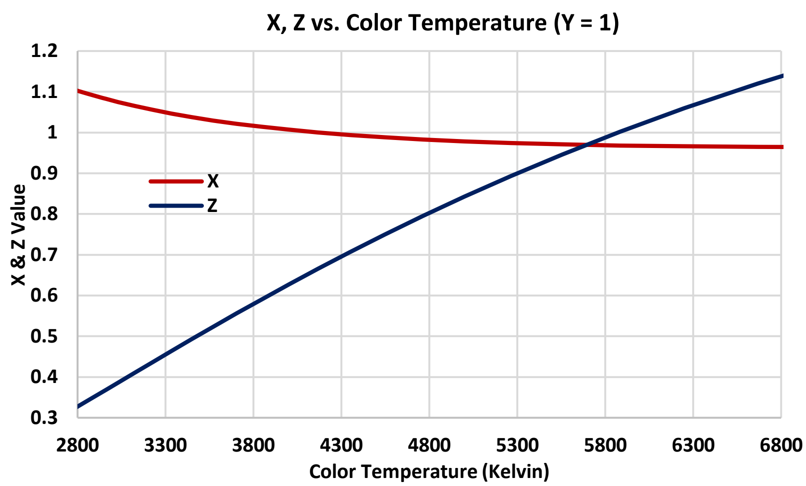


Figure 14 shows the relative power of the red and blue tri-stimulus value where Y=1.

6 References

Reference #	Location	Source
1.	Figure 1	Color Temperature
2.	Figure 2	Fovea centralis
3.	Figure 3	CIE 1931 color space: Color matching functions
4.	Figure 3	Visible spectrum: Spectral colors
5.	Figure 6	Planck’s radiation law
6.	Figure 6	Planck’s Law